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Evaluation of the native femoral neck and stem version reproducibility using robotic-arm assisted direct-anterior total hip arthroplasty

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The intraoperative measurement of the femoral version (FV) has gained attention in wake of an optimised combined version (CV) philosophy. Whereas some data is available utilising different approaches, to our belief this study provides the first in vivo FV data in DA-THA using the MAKO™ robot. To improve the accuracy of the femoral stem version in DA-THA, we want to ask the following question: How effectively can we reproduce the native femoral version in DA-THA using the MAKO™ robot?

The first 125 total hip cases through DAA with the use of the combined anteversion concept and the help of the MAKO™ robot from a single institution, single surgeon from January 2020 to July 2021 were retrospectively analysed. The native version (NV) and broach version (BV) were determined with the use of the MAKO™ preoperative computed tomography planning software.

The data of the NV and BV of 115 withheld patients was normally distributed. The native femoral version ranged from -12° till 33° (mean 7,8° +/- 8,1) and the broach version ranged from -18° till 43° (mean 8,2° +/- 9,9). The Pearson correlation coefficient between the NV and BV was 0,78.

The native femoral version can be reproduced by broaching the proximal femur, in a robotically implanted direct anterior cementless THA, with 78% effectiveness. Stem placement seemed to be more precise with growing experience, however this appeared not to be significant.

Keywords: THA, direct anterior approach, combined anteversion, femoral version, MAKO™ robot.

INTRODUCTION

In the past decades literature has shown correct implant positioning of total hip arthroplasty (THA), and especially of the cup, is an essential factor related to results in THA and patient outcome[1-12]. Although the intended cup position is still a matter of debate[12], cup malpositioning can lead to an increased risk of implant-implant, implant-bone or bony impingement in hip motion. Accordingly, this impingement phenomenon may lead to dislocation, pelvic osteolysis, restricted ROM, faster and more extensive polyethylene wear and loosening and consequently early and higher revision rates[1-13].

Albeit less important, the femoral version has gained attention in wake of the combined version (CV) philosophy. Data shows, whereas inaccurate stem versions (SV) cause impingement and dislocation risk, attaining a desired stem version seems to improve impingement-free ROM and patient outcome[10,14]. Consequently, the intraoperative measurement of SV in DA-THA is essential for surgeons aiming for an optimised CV of cup and stem[15,16]. This narrative study aims to dig deeper in the concept of CV and provides new data in SV reproducibility.

Unfortunately, only a few studies have dealt with optimisation of the prosthetic femoral alignment[17]. The paucity of research devoted to femoral alignment is likely due to the difficult obtaining of accurate measurements of axial rotation from standard radiographs[18]. Furthermore, little has been written regarding the final position achieved with a cementless femoral component, except to recommend approximately 15° of anteversion and so reproducing the average native femoral version[10,19-21]. Moreover, studies have reported a great variation in postoperative (cementless) stem versions ranging from -19° retroversion up to 52° anteversion evaluated on postoperative CT images[7,9,22-27]. Accordingly, the surgeon's intraoperative assessment of femoral anteversion may not be accurate. Not only is there a high variation of the femoral stem version, also the native femoral version in the general population has a wide variety[22].

This study provides the first in vivo FV data in DA-THA using the MAKO™ robot and therefore we believe our trial makes a significant contribution in the concept of CV and providing data in FV accuracy and reproducibility.

To improve the accuracy of the femoral stem version in DA-THA, we want to ask the following question: "How effectively can we reproduce the native femoral version in DA-THA using the MAKO™ robot?

MATERIALS AND METHODS

The first 125 total hip cases after adopting MAKO™ robotic arm assisted surgery were retrospectively selected from a single institution, single surgeon from January 2020 to July 2021. The Accolade II ® stem, a morphometric wedge femoral cementless stem, was used.

Data collected included age, sex, femoral version, stem version, cup version and the combined version. The majority of patients underwent surgery because of osteoarthritis, however patients with dysplasia were also included as they often have high femoral anteversion and therefore are interesting in our study population. Patients who had a prior surgery in case of trauma or femoral osteotomies were excluded.

Moreover, cases in which loss of femoral tracking after broaching occurred (10 patients) were also excluded.

The native version (NV) of the femur was determined with MAKO™ preoperative CT planning software (Stryker Orthopaedics Mahwah). According to the MAKO™ total hip CT scan protocol the pelvis is scanned from the iliac crest distally minimally 180mm below from the lesser trochanter. The knee is scanned in the same single series from 100mm proximally from the joint line downwards including the joint line. Although there are several methods for determining the femoral anteversion as described by Scorcelletti et al. in 2020, the following reference points were chosen: the head centre, the neck centre and the knee transepicondylar epicondylar axis[28].

The procedures were performed through a direct anterior approach and femur-first technique with the use of the combined anteversion concept. The femur-first technique in THA achieves more accurate and more consistent combined anteversion (CA) values in comparison to the cup-first technique. In addition, the conventional cup-first technique is 5,8 times more likely to have dislocation compared to the stem-first technique[20].

When broaching the femur, utilising the box osteotome and sequentially the broaches, the surgeons aimed towards the native version. With the final broach in position, three reference points on the neck trail are collected, from which the navigation software calculates the broach version (BV).

Consequently, the obtained measured versions are broached versions and not stem versions (SV). Previous research noted the BV might slightly differ from the SV with a maximum difference of 2° in uncemented THA via DAA[1].

When discrepancy of more than 10° between NV and BV broaching occurred, we decided to rebroach when CA was in an unfavourable range or when instability was detected/observed. Nevertheless, the initial broach version was recorded and included in the data set.

We aimed for an anatomic reconstruction of the biomechanics apart from the centre of rotation (COR), which was slightly medialized in nearly each case. COR medialization was determined considering acceptable anterior (un)coverage as with respect to the iliopsoas tendon. In extreme varus hips medialization was kept to a minimum, in order to reconstruct the combined offset. On the other hand and for similar reasons, in protrusio cases, the COR was generally lateralised.

The native version (NV) and the broach version (BV) of the femur were collected prospectively, data analysis occurred retrospectively. We used the statistical program SPSS for data analysis. First, the demographic information of our cases was assembled. The Kolmogorov-Smirnov test of normality was performed to look for a normal gaussian distribution of our data. Secondly, all the separated native and femoral versions per casus were plotted. These plotted data were analysed to look for a correlation by the Pearson Correlation coefficient. Thirdly, the difference between the first thirty and last thirty cases were investigated to look for an improvement of the accuracy of the reproducibility of the femoral version with the help of the MAKO™ robot.

The EC was notified before the data was retrospectively collected. We obtained approval from the Ethical Committee.

RESULTS

We included 125 patients in our database. 10 patients were excluded because of loss of femoral tracking after broaching occurred. Consequently 115 patients were withheld for further analysis. The mean age was 66 years (standard deviation of 13 years). 50% were men and 50% were women. There was a normal gaussian distribution of our data as shown in figure 1 and 2. This was confirmed by using the Kolmogorov-Smirnov test of normality. The Kolmogorov-Smirnov values for the distribution of respectively the NV and BV were 0,067 (p-value: 0,66) and 0,075 (p-value: 0,52) which means the NV- and the BV-data were not significantly different from a normal gaussian distribution.

The NV ranged from -12° till 33° with a mean native version in 115 patients of 7,8° (SD +/- 8,1). The BV of the stem ranged from -18° till 43° with a mean femoral broach version of 8,2° (SD+/- 9,9). These data are plotted in a scatter plot as shown in figure 3. This visualises the relation between the native version and femoral broach version. The orange line indicates a perfect situation in which one could restore the native version in all patients (Pearson Correlation Coefficient of 1, the first bisector). The blue points indicate the native version of all 115 patients (x-axis) in relation to their associated femoral broach version (y-axis). The blue line indicates the global relation in our study population. A Pearson correlation coefficient of 0,78 was calculated, which means that the native femoral neck version was reproduced with the broach with nearly 80% effectiveness.

Finally, the difference between the first thirty and last thirty cases were investigated by using the Fisher-Z-transformation to look for an improvement of the accuracy of the reproducibility of the femoral version with the help of the MAKO™ robot. The Pearson correlation coefficients for the first thirty and last thirty cases were respectively 0,7726 and 0,7864. The Fisher-Z-transformation test was used to look for a significant improvement. The Fisher Z-transformation p-value was 0,42. Consequently we can conclude there was only a slight tendency towards improvement over time, but not a significant difference.

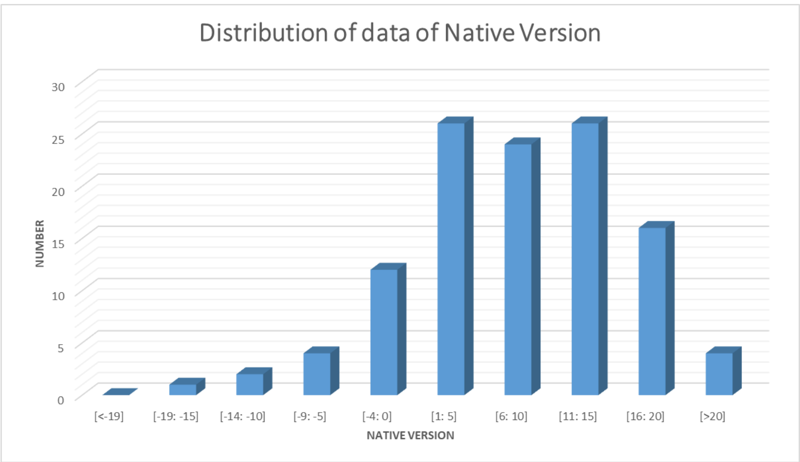

Figure 1. — Distribution of data of native version

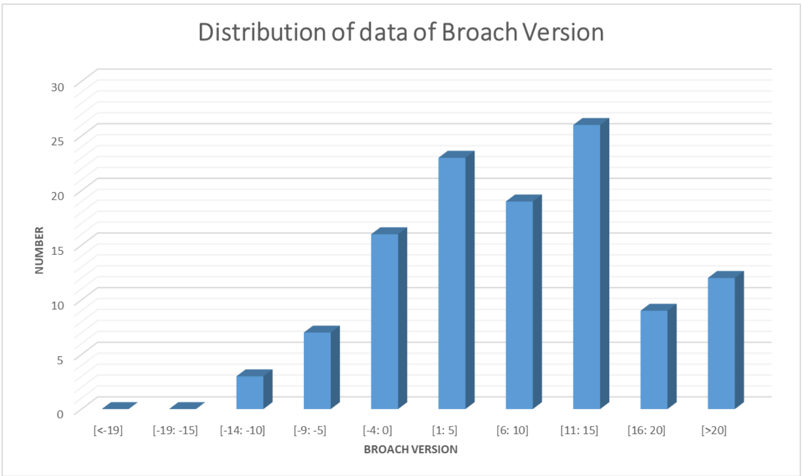

Figure 2. — Distribution of data of femoral broach version

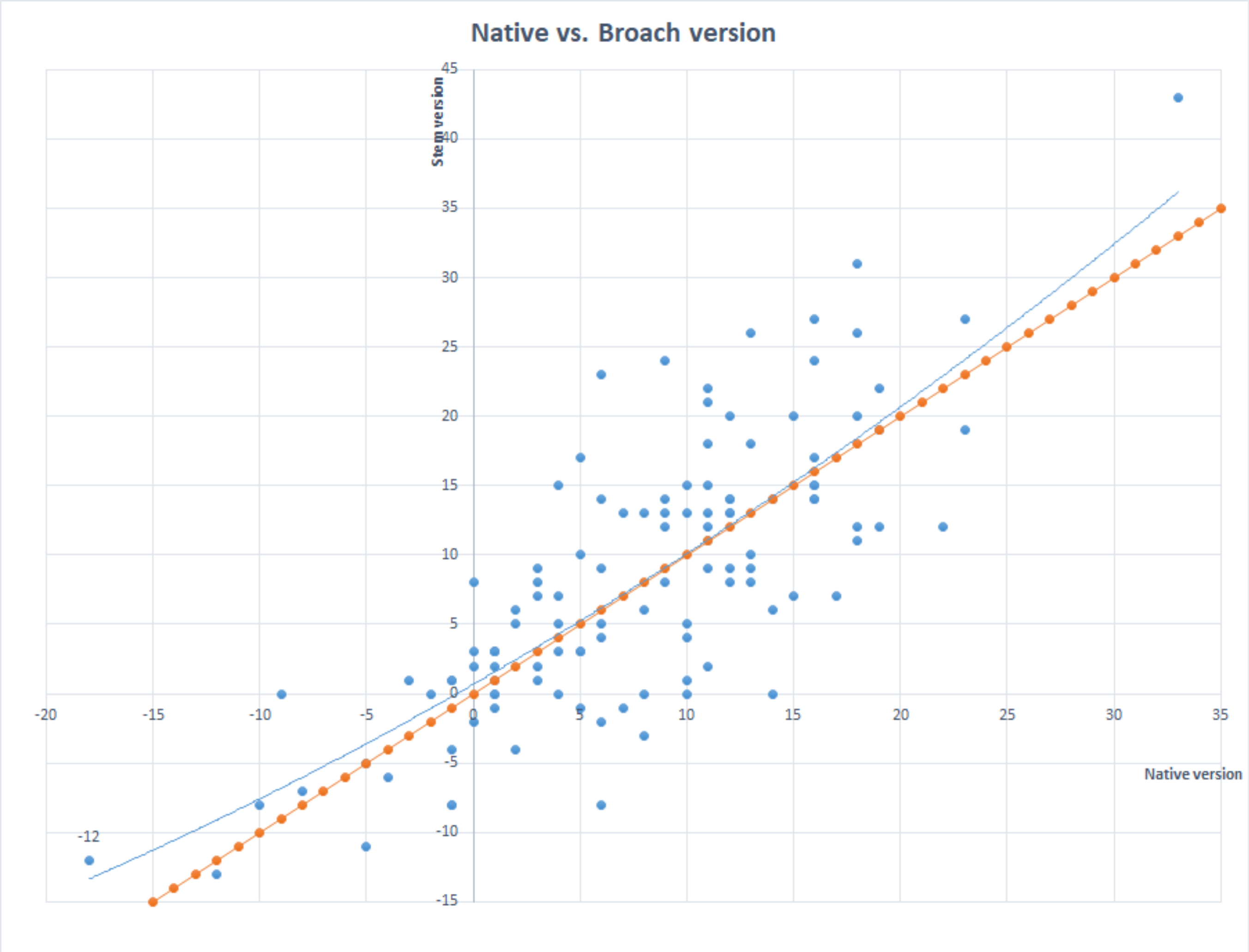

Figure 3. — Scatter plot: native vs. stem version. Orange line indicates a perfect situation (Pearson Correlation Coefficient of 1) in which one could restore the native version in all patients. The blue points indicate the native version of all 115 patients (x-axis) in relation to their associated broach version (y-axis). The blue line indicates the global relation in our study population.

DISCUSSION

There are several potential limitations in this study. First, we used a single cementless stem from one manufacturer in this research. The Accolade® stem is a titanium alloy stem from Stryker®. It is a morphometric wedge femoral cementless stem with a proximal part that provides the stabilisation. Therefore, our findings might not be transferable to other stem designs.

Secondly, the number of patients in this study was 125. A small sample size may not reflect the variability of patient anatomies. The single-surgeon single-centre cohort may limit the generalisability of these results.

Thirdly, anteflexion and retroflexion of the stem cannot directly be measured with the actual MAKO™ software. Especially in straight tapered stems (which was not used in this research) there is little control about the anteversion of the femur since it follows the flexion and bowing of the proximal femoral cortex (‘the best-fitting position’). However, the effect of stem flexion on stem version is thought to be relatively low[1,10,23,29,30].

Fourth, we collected data intraoperatively by taking three reference points, as described in the methods section: the head centre, the neck centre and the knee transepicondylar epicondylar axis. Where the head centre has a low inter-observer variability for the measurement of the NV, unfortunately the neck centre has a high inter-observer variability (especially in the CAM deformities). Also changes in neck centre may distort/impact version measurements significantly[1,28]. Therefore, there might be a variability in the collection of the neck centre points between patients.

Fifth, this is the first research providing in vivo data regarding attained intra-operative stem versions utilising

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a direct anterior approach for THA. Intentionally, the first cases after adopting the MAKO™ technology were incorporated in our data in order to minimise the possible learning effect accompanied with continuous data-feedback from the robot.

Finally, and most importantly, the clinical relevance of this study is dependent on the assumption that the various papers proposing the use of combined femoral and acetabular anteversion for the optimal position of the implants are correct. Therefore, we cannot exclude that the extreme versions were unconsciously corrected towards the average version, aiming towards an optimal CA. For example, cases with a BV of more than 30° of anteversion, the cup version had to be set to retroversion to meet a satisfactory CA range criterion (risking posterior dislocation). Similarly, when the BV angle was less than 0° (retroversion), the cup had to be set more than 30° anteversion (risking insufficient coverage of the posterior area of the cup)[17,31]. This might be a tendency of the surgeon that we cannot completely rule out.

On the other hand, we achieved fair data quantity and quality with 115 procedures analysed. Because of the preoperative CT measurements and intra-operative MAKO™-robot provided information, we believe the collected data is high quality. The measurement of the native and broach versions in the same patient position and within the same reference plan is another strength of our study. Consequently, deviations in recording the data were minimised.

Finally, we used intraoperative robotics to verify the best position of the cup and stem. The orientation of the femoral stem can be improved significantly using robot-assisted THA, compared with manual positioning[32]. To our knowledge so far, no study has analysed the reproducibility of the native femoral version in robotically implanted DAA THA. We therefore believe that our trial makes a significant contribution to the understanding of the concept of robotically implanted cementless THA with the use of the DAA.

The majority of hip cases were patients with osteo-arthritis. Although dysplastic hips were also included in the data, the overall native version (NV) and broach version (BV) distribution seems to be normally distributed. For 115 withheld cases there was a mean native version of 7,8 (SD +/- 8,1) and a mean femoral broach version of 8,2 (SD+/- 9,9). The mean difference between the native femoral version and the finale broach version was 0,3.

It remains difficult to compare our mean native and broach versions with earlier published literature. Because different studies have reported a high variation in postoperative cementless stem versions ranging from -19° retroversion up to 52° anteversion[1,9,11,20,22].

Moreover, in the clinical trial of Worlicek et al, the authors confirmed this wide range of rotation in cementless stems from -9.9° retro- to 46.5° anteversion. Worlicek investigated 55 THA patients with a cementless, straight, tapered stem and found that the mean difference between native femoral version and final implant was 1.9° (+/- 9.5), with a range from −20.7° to 21.5. In contrast, they observed a mean difference between the final broach and implant version of -1.9° (+/- 3.5), with a range from -12.7° to 8.7°. Therefore, Worlicek stated that the native femoral version significantly differs from the final anteversion of a cementless, straight, tapered stem and therefore is not a reliable reference in cementless THA. Measuring the anteversion of the final "fit and fill" broach is a feasible assistance in order to predict final stem anteversion intraoperatively[1].

Several factors could be brought forward to explain mismatches between the measured native and broach version in some cases. First, the positioning of the patient and surgical error (eye-balling) are consistent ineluctable factors causing NV-BV mismatch.

Secondly, not to forget, the combined version is approach-dependent, as is the cup version. In the DA-THA the CV should be 23.36° +/- 4.58°, in the posterolateral approach CV should be 37.59°+/- 4.62° while using the anterolateral approach the CV should be 28.55° +/- 6.91°. These values show significant differences attributable to the surgical approach and to hip's morphological features[33]. Consequently, the femoral broach version (BV) is also presumed to be approach-dependent. Therefore, the surgeon might unconsciously correct towards the average version, aiming towards an optimal CA. This might be another possible explanation for a mismatch between NV and BV.

In addition, muscle derangement and soft tissue damage inevitably leads to potential instability. In particular, the posterior approach usually is associated with higher cup and stem versions to prevent posterior instability. In the posterior approach, surgeons not only deliberately increase cup and stem version to compensate for stability, but accordingly also to increase impingement-free ROM.

In particular for the direct anterior approach (DAA) some factors could be brought forward to explain possible mismatches between NV and SV. With the steady growth of THA performed through a DAA and the concept of the 'femur first technique', less attention was given to the old standard 'desired 15°' stem version.

Several reasons could be put forward explaining this change in surgical philosophy.

First, the DAA is a muscle-sparing approach, resulting in an inherent stable new joint. Therefore, a suboptimal CA will still result in a well-functioning stable implant.

Second, femoral exposure is attained with the patient's leg in a figure-of-four position, which might not be the most reliable leg position. When draped and in figure-of-four positioning it may complicate the estimation and broaching of the femoral version in comparison to an anterolateral or posterior approach. With the foot hanging off the table, obesity, improper superior capsular release, the transepicondylar axis (TEA) in the knee will not position perpendicular with the floor and the TEA will display more internally rotated. Therefore, when setting the same angle of the broach with the floor, this situation will cause excessive anteversion. Measures such as a footrest at the opposite side of the table could prevent this pitfall.

Third, DAA is commonly applied with uncemented stems, where rotational alignment is less easily controlled, compared to cemented stems. The uncemented stem regularly tends to follow the native version.

In addition, the proximal femoral anatomy (femoral bowing) influences the version. Unnatural torsion of the stem will cause less filling of the canal and therefore potentially an undesired stem version. However, as mentioned before, the effect of stem flexion on stem version is thought to be relatively low[1,23,30].

Lastly, uncemented stems are broached with the "best fill and fill" concept in mind. Preventing undersizing the stem will reduce the risk of subsidence, on the other hand it will create variability in the stem version. Optimising femoral fill will inevitably cause less control of femoral rotation. Consequently (even experienced) DAA surgeons are looking for techniques and tools ameliorating the desired femoral version in DAA[9,11,24,34,35].

The native femoral version is fairly reproducible through a direct anterior approach (DAA). The Pearson correlation coefficient in our DA-THA cases was 0,78 and demonstrates that the femoral version reproducibility could be obtained with 80 % accuracy. Therefore, the DA-THA-surgeon can rely on this MAKO robot-assisted technique.

To our belief there is no in vivo data investigating the accuracy and reproducibility of the femoral version using the direct anterior approach (DAA). We only found an ex vivo study of the native version and stem version of THA using the direct anterior approach on 30 cadavers of 2009 of Nogler et al.[36,37].

All other data concerned THA using anterolateral or posterior approaches[13,24,34,35,38]. Our correlation of 78% seems higher than reported in an article with the same study design, however with the use of different total hip approaches[39]. Marcovigi et al. published a recent article of 2019 in which they investigated the relation between the native version and stem version in THA, however through the anterolateral and posterolateral approaches. They published a mean femoral NV of 5.0° ± 9.6°, and SV of 6.4° ± 9.7°. The average difference between NV and SV was 1.6° ± 9.8°. The authors found a moderate correlation between NV and SV ($R = 0.48$, $P < .001$). SV was between 5° and 20° in 174 patients (48%). Mean CV was 28.2° ± 7.9°. A strong correlation was found between SV and CV ($R = 0.89$, $P < .001$). Marcovigi concluded the SV in anterolateral and posterolateral approaches is moderately correlated with the native version and that the SV is highly variable. The SV can be partially influenced by the surgeon[38].

Furthermore, the reproducibility of the native femoral version and therefore the surgical precision seems to slightly increase with feedback delivered by the MAKO™-robot. When comparing the first thirty and last thirty cases a minor improvement was noted (Pearson correlation coefficients of respectively 0,7726 and 0,7864). However, this increment was not significant (p-value of Fisher-Z-transformation of 0,42). Consequently, we can only suggest there was a little tendency towards improvement over time, but not a significant difference.

It is still not elucidated whether to go for a restoration of the anatomical version or an impingement-free ROM?[39]. In this study we aimed for the first, although we recognise that this might not be the optimal version in case of an impingement-free ROM. Up until now it is not fully unravelled which concept to follow. Several unresearched factors such as the influence of soft tissue as the capsule on the version still need to be researched[40]. However current trends in THA component positioning directs more and more towards reconstruction of the anatomy and biomechanics. Due to the inherent stability with muscle-sparing approaches, this philosophy is specifically followed in DA-THA.

CONCLUSION

Despite the listed limitations and potential mismatches between the femoral native and broach versions, the intraoperative measurement of the femoral version remains crucial for DA-THA surgeons aiming for an optimised combined version. This study provides the first in vivo femoral version data in DA-THA using the MAKO™ robot (based on preoperative CT scan imaging) and therefore we believe our trial makes a significant contribution.

The native femoral version can be reproduced by broaching the proximal femur, in a robotically implanted direct anterior cementless THA, with nearly 78% effectiveness. Stem placement seemed to be more precise with growing experience, however this appeared not to be significant.

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